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TITLE: Electromagnetic Properties of High T(C) Superconductors

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STATEMENT "A" per Dr. Michael Shlesinger
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1. PROJECT DESCRIPTION

During the first part of the grant period, we have focussed on the nonlinear and frequency dependent response of strongly disordered materials.

We have chosen the alloy system $Ge_{1-x}Au_x$ for detailed studies of the dynamics because the static properties, and the development of the localized states with decreasing temperature are well understood and specimens can be prepared at UCLA using an evaporator available to us.

We have measured the electric field dependent of the conductivity $\sigma(E)$ for some $Ge_{1-x}Au_x$ evaporated alloy films near the metal-insulator transition. In our work this occurs near the nominal composition x = 0.12. Both dc and pulsed field methods were used.

We have found that the conductivity is strongly nonlinear at temperatures, and have interpreted our results in terms of electron heating effects.

INVESTIGATION CONCERNS

During the second part of the grant period we have been investigating the high frequency properties of various high T_c superconductors. The key parameter which is studied in the micro- and millimeter wave spectral range is the surface impedance Z_s. It is one of the parameters which reflects the electrodynamics of the superconducting state. At the same time it is perhaps the most important technical parameter which determines the application potential of the superconductors for high frequency passive components and devices. KEYWORDS: SUPERCONDUCTORS; ELECTROMAGNETIC PROPERTIES. (RH)

The surface impedance is defined as

$$Z_s = \frac{E_o}{\int_0^\infty j\,dx} \qquad (1)$$

where E_o is the electric field of the surface, j the ac current in the sample and the x direction is perpendicular to the surface. Z_s is, in terms of the complex conductivity $\sigma = \sigma_1 - i\sigma_2$, given by

$$Z_s = \left(\frac{\mu_o \omega}{\sigma_1 - i\sigma_2} \right)^{1/2} = R_s + iX_s \qquad (2)$$

where μ_o is the permeability of free space, R_s and X_s are the surface resistance and surface reactance, and ω the measuring frequency.

The surface resistance has been calculated in the local limit by Mattis and Bardeen, and $R_s(T)$ is in good agreement with experiments conducted on classical superconductors. For the high temperature superconductors, the mean free path is comparable to the coherence length ξ, and consequently finite mean free path effects are important, and have to be taken into account when experiments are compared with the various theories of the superconducting ground state.

Our experiments are conducted by using resonant structures, with the superconducting material forming part of the structure. Both cavity endwall and cavity perturbation techniques have been utilized, they give somewhat different information on R_s and X_s. In all cases R_s and X_s is determined using a configuration where these parameters refer to electric currents flowing in the planes (if thin films are investigated).

$R_s(T)$ measured by us on a ceramic, sputtered thin film and laser ablated film is displayed in Fig. 1. One observes a finite residual resistance as $T \to 0$, and $R_s(T)$ depends also strongly on the film quality, with laser ablated films -- the highest overall quality -- giving the lowest $R_s(T)$ values.

The large R_s for the majority of materials is due to a second phase or due to grain boundaries which act like Josephson coupling between the grains. We have developed a simple model of grain boundary effects on the surface impedance of thin films, the material is modeled as a network of superconducting grains coupled by Josephson junctions, which are described using the standard resistively shunted junction model with negligible capacitance.

For laser ablated films, grain boundary effects are not important, and $R_s(T)$ can be compared with the various theories of the surface impedance, i.e. with a calculation based on the Mattis-Bardeen model, and with calculations with finite mean free path effects with various gap values. Our experimental results lie below $R_s(T)$ arrived at for a realistic model, with $\ell/\pi\xi_o = 1$ and $2\Delta = 3.5k_BT_c$ (corresponding to $\xi_o = 16Å$ and $\ell = 50Å$, both parameters refering to the in-plane parameters). This suggests that Δ is larger than the weak coupling limit, and a value $2\Delta \sim 5k_BT_c$ appears to describe our results well. Consequently, surface impedance studies suggest, that $YBa_2Cu_3O_7$ is in the strong coupling limit with Δ exceeding well the BCS value. Our results also convincingly rule out drastic deviations from a gap which opens up along the entire Fermi surface. We note however, that the experimental configuration employed by us leads to ac current in the CuO_2 planes, and consequently, no information is gained on the ac losses for current perpendicular to the planes.

Our results have obvious implications as far as the application potential of these materials is concerned. We have found that at microwave frequencies the losses can be lower by more than one order of magnitude than Cu at the same temperature both in $YBa_2Cu_3O_7$ and in the $T\ell$ based films.

I believe that future work on the high frequency properties of high temperature superconductors is fully justified. The stage is set for construction and testing of simple passive microwave devices, and to correlate the device characteristics with the loss characteristics of films and also with losses which occur in the dielectric substrates.

2. PUBLICATIONS DURING THE GRANT PERIOD

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3. PERSONNEL SUPPORTED BY THE GRANT

1.	Dr. John Cooper	Postdoctoral Associate
2.	Dr. John Carini	Postdoctoral Associate
3.	Ward Beyermann	Graduate Student
4.	Sang Woog Cheong	Graduate Student
5.	Larry Drabeck	Graduate Student

4. FINAL INVENTORY OF PROPERTY

None

5. FINAL PATENT REPORT

None